SELECTION OF THE CUPOLA FURNACE AND FABRICATION OF THE MODEL

MINI PROJECT REPORT - 2009

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ABSTRACT

A cupola or cupola furnace is a melting device used in foundries that can be used to melt cast iron, ni-resist iron and some bronzes. The cupola can be made in almost any practical size. The size of the cupola is represented or taken on the basis of the melting capacity and the diameters and can range from 18 inches to 13 feet. The overall shape is cylindrical and usually arranged vertically, supported by 4 legs.

Cupola has very complexed reactions. Scrap metal and flux are added from the charging door and hot air blasted through the tuyeres which actually controls the overall heat. Slag is collected from the slag hole and hot molten metal from the tap hole. The bottom of the cylinder is fitted with doors which swing down and out to 'drop bottom'. The top where gases escape can be open or fitted with a cap to prevent rain from entering the cupola.

The shell of the cupola, being usually made of steel, has refractory brick and refractory patching material lining it. The bottom is lining in a similar manner but often a clay and sand mixture may be used, as this lining is temporary. The bottom lining is compressed or 'rammed' against the bottom doors.

By the mini project we are aiming to fabricate a model of cupola furnace selected on the selection criteria.
CHAPTERS

1. INTRODUCTION
   FURNACES
   ABOUT CUPOLA
   OBJECTIVE OF PROJECT

2. CUPOLA IN GENERAL
   STRUCTURAL DETAILS
   CUPOLA OPERATIONS
   PREPARATION OF CUPOLA
   LIGHTING THE FIRE IN THE COKE BED
   CHARGING OF CUPOLA
   MELTING
   SLAGGING AND METAL TAPPING
   DROPPING DOWN THE CUPOLA BOTTOM
   ZONES OF CUPOLA
   EFFICIENCY OF CUPOLA
   ADVANTAGES AND LIMITATIONS
   QUALITY CONTROL

3. SELECTION CRITERIA OF CUPOLA FURNACE FOR FABRICATION
   3.1 FABRICATION DIAGRAM
   3.2 MELTING CAPACITY
   3.3 MATERIALS REQUIRED

4. FABRICATION DETAILS

5. CONCLUSION

6. BIBLIOGRAPHY
LIST OF TABLES
1. TABLE 3.1 [1]
LIST OF FIGURES

1. Fig 2.1
2. Fig 3.1
CHAPTER 1

INTRODUCTION

Before pouring the metal into the mold, the metal is to be in the molten or liquid state. A furnace is used to melt the metal. A foundry furnace rather, remelts the metal to be cast. It is not meant for carrying out basic melting operations which convert an ore into usable metal. Whereas blast furnace performs basic melting (of ore) operation, an electric arc, electric resistance etc. Different furnaces are employed for remelting ferrous and non-ferrous materials. Heat in a remelting furnace is created by, combustion of fuel, electric arc, electric resistance etc. A furnace contains a high temperature zone or region surround being insulating minimizes heat losses to the surroundings. Metal to be remelted is placed in the high temperature region of the furnace.

The development of blast furnace for the reduction of iron ore gave birth to iron founding. At first, pig iron from the blast furnace was directly used for making iron castings. As time went on and the use of iron castings were very common, smaller shaft type furnaces were used for remelting pig iron specifically for making small gray iron castings. Thus evolved the cupola. The first English patent on a cupola was granted in 1794.

Cupola is employed for melting scrap metal or (over90% of) the pig iron used in production of iron castings. It is an economical furnace for the production of gray cast iron, modular cast iron and some malleable iron castings. Besides iron castings, cupola can be used for melting some copper alloys also. Cupola can be employed in duplexing and triplexing operations for making steels. Duplexing and triplexing melting operations employ and three furnaces respectively. Cupola is obtained in different sizes. Cupola can be operated for as long a time as may be required to produce a given amount of iron. Cupola does not produce metal of uniform quality. Fuel for cupola is generally a good grade low-sulphur coke, anthracite coal or carbon briquettes.

The objective of project is to select a cupola furnace for fabricating of the model using the selection criteria. The fabricated cupola furnace model should be able to explain all the working conditions.

The cupola is one of the main reasons that hasten up the industrial revolution. It also hasn’t lost the significance by the arrival of new foundry furnaces. So we decide to fabricate the model of cupola. Our college would benefit from it since the new syllabus includes foundry practise for all the students. It would be easier for them to understand the working conditions and to learn them.
CHAPTER 2
CUPOLA

2.1 STRUCTURAL DETAILS

A cupola is a cylindrical shell constructed (welded or riveted) form boiler plate (6 o 10 mm thick), is open at both its top and bottom and is lined with firebrick and clay. At bottom the cupola is supported on cast iron legs; the bottom opening of cupola is closed by cast iron which can be made to open or close and are supported (when closed) by an iron prop (or upright). The bottom opening doors swing out of the way after the melting operation is over and thus the contents left in the cupola drop down through the opening (Thus formed). Air from the blower (not shown) comes through the blast pipe and enters wind box which surrounds the cupola and supply’s air evenly to all the tuyeres.

Tuyeres extend through the steel shell and refractory wall to the combustion zone and supply air necessary for combustion. The total cross sectional area of the tuyeres is about one fifth to one-sixth of the cross-sectional area of the cupola. Tuyeres have dimensions 50 mm x 150 mm or 100 mm x 300 mm. Cupola up to 75 cm diameter may have three to four where as larger ones are fitted with eight, ten or even more number of tuyeres. Tuyeres may be fitted in one or more number of rows. Auxiliary tuyeres sometimes provided to raise melting efficiency. The volume of air passing to the combustion zone can be measured with the help of a volume meter. Normally air pressure is 12 to 16 in., water gauge for small and medium sized cupolas and 16 to 35 in., water gauge for large cupolas. A cupola using 1 to 1 ratio of iron to coke consumes about 800-900 cubic meters of air to melt one ton of iron.

There is a tap hole in the cupola from where the molten metal is taken out pour into the molds. The fire in the cupola is also lit through the tap hole. Opposite the tap hole and a little higher (but about 25 cm below tuyere centre) is the slag hole. Slag being lighter than metal, floats over the molten metal and is removed through the slag hole.

Cupola remains either open or has a metal shield or a spark arrester at its top. In addition, a cupola is provided with a charging platform and a charging door at suitable heights to feed the charge in cupola. Cupola capacities (size) vary from 1 to 15 tons (or even more) of melted iron per heat. Certain small cupolas having a capacity of ½ to 1 ton are better called cupolettes. Cupolettes have a height which varies from 2.5 to 4 metres. Cupolette may be tilted to horizontal position as well. The height of cupola is commonly about 6 metres. The inside diameters of common cupolas with much smaller and larger diameters have been operated. Sometimes a cupola may be fitted with a collector, filter and precipitator to minimize atmospheric pollution.
2.2 CUPOLA OPERATIONS

A cupola heat includes not only the actual melting operation but all the operations which precede and follow the period during which iron is being melted. A certain cycle of events occurs each time a heat is made, including the following:

1. Preparation of the refractory lining, bottom, and tap hole and slag hole
2. Lighting and burning in the coke bed
3. Charging
4. Melting
   a. Starting the air blast
   b. Charging
5. Tapping and slagging
6. Dropping the bottom

2.2.1 PREPARATION OF CUPOLA

The bottom door is dropped to open. The contents in the cupola left from the previous melting operation are dumped under the furnace and removed. Slag, coke and iron sticking to the side walls of the furnace are chipped off. Damaged firebricks are replaced by new ones. The damaged furnace refractory lining is patched and repaired. Eroded refractory lining at the combustion zone etc., is filled with a pneumatically operated gun which blows refractory patching mixture at sufficient velocity so that it sticks properly with the lining. A typical refractory mixture for patching consists of two pacts by volume ganister and one part by volume of fine clay.

Cupola block is used for original lining. Cupola block has the following composition.

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>52-62%</td>
</tr>
<tr>
<td>Alumina</td>
<td>31-43%</td>
</tr>
<tr>
<td>Titanium</td>
<td>1.5 to 2.5%</td>
</tr>
<tr>
<td>Fluxing oxide</td>
<td>3 to 6%</td>
</tr>
</tbody>
</table>

Once the furnace lining is reconditioned, the bottom opening door is closed and duly supported (using a prop). A layer of (about 10 cm.) tempered sand (having 3 to 6% moisture, 60 or more permeability and about 0.5 kg/cm² green strength) sloping towards the tap hole is rammed over the bottom (door). The slope provides better (molten) metal flow. Ramming should be uniform and proper to avoid any leakage of molten iron through the bottom opening door.
2.2.2 LIGHTING THE FIRE IN THE COKE BED

Cupola is started, i.e. fixed about 3 hrs before the molten metal is needed for pouring into the moulds. For starting the cupola, soft and dry pieces of wood are placed on the sand bed rammed above the bottom opening door. Coke is placed over the wooden pieces and wooden pieces are ignited either through some other opening, level the bottom. Air necessary for combustion of coke enter from the tuyeres when the initial coke is burning well, an additional amount of the same is added to the desired height. The coke bed height is roughly of the order of 75 cms, above the tuyeres level. Coke is added through the charging door and the coke bed height can be measured from the charging door using a chain or rod. Besides using wooden pieces for initiating fire in the cupola, the other methods which are used for the purpose employ

(1) Electric spark ignitor,
(2) Gas torches.

2.2.3 CHARGING OF CUPOLA

After the coke bed is properly ignited, the cupola is charged from the charging door. Charging of cupola means adding alternate layers (i.e. charges) of limestone (i.e. flux), iron (i.e. metal) and coke (i.e. fuel), up to the level of charging door. Flux is a substance which aids forming slag to remove impurities and retards oxidation of iron. Flux lowers the melting point of slag and increases its fluidity. Slag forms as the oxides and other impurities accumulate during melting operation. The commonly employed flux is limestone (CaCO3). Other fluxing materials which can be used are sodium carbonate (Na2CO3), fluorspar (CaF2), calcium carbide (CaC2) and dolomite, containing limestone and magnesium carbonate.

All these fluxes are basic and thus should not be added in large amounts; otherwise they will attack the acid refractory lining of an ordinary cupola. Ordinarily the slag is acidic and contains about 40 to 50% silica. The quantity of limestone which is used as flux varies from 2 to 4% by weight of the metal (i.e. iron) charge. A fuel employed for combustion in the cupola can be

_ a good grade of low sulphur coke,
_ Anthracite coal, or
_ Carbon briquettes.

The ratio of metal to fuel by weight ranges in various practices from about 4 : 1 to 12 : 1 depending upon the quality of fuel available. The melting ratio of 10: 1 means that to melt 10 ton of iron, one ton of coke is required.

Metal charge may consist of
- Pig iron
- Cast iron scrap
- Steel scrap
- Returns (i.e. sprue, gates, rises, defective castings etc.)

A typical metal charge contains
- Pig iron – 30%
- New scrap iron – 30%
- Returns – 40%

2.2.4 MELTING

After the cupola is fully charged, a soaking period of about 30 minutes to one hour is given to permit the charge to preheat. Blowers are not started during the soaking period; the air only enters through tuyere peep holes and the spout opening. At the end of soaking period, the blast is turned on. The coke becomes fairly hot to melt the metal charge. Droplets of iron can be seen falling past the tuyere peepholes. After the air blast has been on for 10 minutes, molten iron starts accumulating in the hearth and appears at the tap hole. The tap hole is closed with the bott (i.e. a plug) and the molten iron is allowed to collect for about five minutes. Adequate care and precautions are required to prevent the first iron from freezing in comparatively colder tap hole.

2.2.5 SLAGGING AND METAL TAPPING

After enough molten iron has collected, the slag hole is opened; the slag comes out of the slag spout, is collected in a container and disposed of. The bott inserted in the tap hole is knocked out and the first molten iron which is often cold is cast into pigs rather than ladled and poured into the molds. As the air blast continues, melting progresses and the molten iron is tapped for pouring into the molds. The cupola charge consumes with the passage of time and thus additional charge of limestone, iron and coke is dropped through the charging door at a rate at which the charge consumes so that cupola remains always full of charge. The tap-hole which normally remains closed with a bott is opened intermittently and the molten iron is allowed to flow into a ladle. Intermittent tapping is usually accompanied by intermittent slagging.

2.2.6 DROPPING DOWN THE BOTTOM

The end of cupola heat begins with cessation of charging. The stack contents are melted down until about one or two charges remain above the coke bed. During this period the air blast is often reduced. The bottom doors are then dropped, and the contents fall to the floor under the cupola. Water is sprayed over the white-hot drop to prevent it from damaging the legs and bottom. In some cupola
installations the remains fall to the bucket and is removed from the foundry and quenched with water. Metal and coke from the drop may be recovered and worked into charges gradually in succeeding heats.

### 2.3 ZONES OF CUPOLA

The different zones of cupola are marked in the fig.2.1.

Well is a sort of well of molten iron; the molten iron collects in this zone before being tapped. The well is situated between the tapered rammed sand bottom and the bottom of the tuyeres.

Superheating, Combustion or Oxidizing Zone: It is situated normally 15 cm to 30 cm above the tuyeres. All the oxygen in the air blast is consumed here owing to the combustion taking place in this zone. Thus a lot of heat is liberated and supplied from here to other zones. Oxidation of manganese and silicon evolve still more heat. The chemical (i.e. exothermic) reactions which occur in this zone are:

\[
\begin{align*}
C + O_2 \quad \text{(from air)} & \rightarrow \quad CO_2 \quad + \text{heat} \quad \quad \quad \quad \quad - 1 \\
2Mn + O_2 \quad \text{(from air)} & \rightarrow \quad MnO_2 \quad + \text{heat} \quad \quad \quad \quad \quad - 2 \\
Si + O_2 \quad \text{(from air)} & \rightarrow \quad SiO_2 \quad + \text{heat} \quad \quad \quad \quad \quad - 3 \\
\end{align*}
\]

The exothermic reaction [1 only] produces 14452 BTU of heat per pound of carbon in the coke at 60°F. The temperature of the combustion zone varies from 1550°C to 1850°C.

Reducing Zone or Protective Zone: It extends from the top of combustion zone to the top of coke bed. It has reducing atmosphere and thus protects from oxidation, the metal charge above and the dropping through it. An endothermic reaction takes place in this zone, in which some hot CO\(_2\) moving upward through hot coke gets reduced.

\[
CO_2 \quad + \quad C \text{ (coke)} \quad \rightarrow \quad 2CO \quad \quad \quad \quad \quad \text{Heat} \quad - 4
\]

This reduces the heat in the reducing zone and consequently it has a temperature only of the order of 1200°C. The heat absorbed by the endothermic reaction is of the order of 2910 BTU per pound of total carbon in the CO at 60°F. Along with CO\(_2\), N\(_2\) moves upward the combustion zone to the reducing zone but it does not take part in the reaction.
Melting Zone: Melting zone starts from the first layer of metal charge above the coke beds and extends up to a height of 90 cm. or less. Iron (metal charge) melts in this zone and trickles down through the coke bed to the well zone. The temperature in the melting zone in this zone, the molten iron picks up carbon. As per the following reaction taking place in this zone, the molten iron picks up carbon.

\[ 3\text{Fe} + 2\text{CO} \rightarrow \text{Fe}_3\text{C} + \text{CO}_2 \]

Preheating Zone: Preheating zone starts from the melting zone and extends up to the bottom of the charging door. Preheating zone contains cupola charge as alternate layers of coke, limestone and metal. Gases like CO$_2$, CO and N$_2$ rising upwards from combustion and reducing zones preheat the cupola charge to above 1100°C. Thus preheated charge gradually moves down in the melting zone.

Stack Zone: Stack zone extend from the preheating zone to where the cupola shell ends and spark arrestor is attached. Hot gases from cupola pass through the stack zone and escape to atmosphere. Stack gases will normally contain about equal amounts of CO$_2$ and CO which is 12% each and the rest is 76% is nitrogen.

### 2.4 EFFICIENCY OF CUPOLA

The % efficiency of a cupola

\[
\text{efficiency} = \left( \frac{\text{heat utilized in preheating, melting and superheating}}{\text{heat input due to heat in the coke} + \text{heat involved due to oxidation of C, Fe, Si and Mn} + \text{heat in the air blast}} \right) \times 100
\]

The term heat in the air blast is more purposeful with regard to a hot blast cupola. The efficiency of a cupola varies from 30 to 50%. The cupola efficiency can be increased by the use of preheated air. The temperature to which the air is to be heated may be off the order of 350 to 500 degree Fahrenheit’s or even higher. The use of preheated air improves combustion, increase the calorific value of coke and metal charge input.

### 2.5 ADVANTAGES AND LIMITATIONS

Widespread use of cupola for grey-iron melting rests upon its unique advantages, which include:

1. Continuous melting. Foundry production is facilitated since a ladle of molten iron may be tapped from the furnace at regular intervals. The flow of molten metal and molds for pouring may be synchronised for quantity production as required by the automotive, agricultural equipment and similar industries.
2. Low cost of melting. Raw materials and operating costs are lower than on any other type of melting furnace producing equivalent tonnage.

3. Chemical composition control is possible by proper furnace operation with continuous-melting.

4. Adequate temperature control for fluidity in pouring castings can be obtained.

Certain limitations also are characteristics of the cupola furnace. Low carbon percentages in the iron below about 2.80% C are difficult to attain because of direct contact of molten iron and the carbonaceous fuel. Some alloying elements such as chromium are in part loss by oxidation of cupola. Higher temperatures are obtained with air-furnace and arc-furnace melting. Since molten iron and coke in contact with each other, certain elements (like Si, Mn) are lost while others (like sulphur) are picked up. This changes the final analysis of molten iron.

2.6 QUALITY CONTROL

During the production, samples may be taken from the metal and poured into small molds. A chill wedge is often poured to monitor the iron quality. These small, approx 18 mm (3/4") wide x 38 mm (1-12") tall triangular shaped pieces are allowed to cool until the metal has solidified. They are then extracted from the sand mold and quenched in water, wide end first. After cooling in the manned the wedges are fractured and the metal coloration is assessed. A typical fracture will have a whitish colour towards the thin area of the wedge and grayish colour towards the wide end. The width of the wedge at the point of demarcation between the white and gray areas is measured and compared to normal results for particular iron tensile strengths. This visual method serves as a control measurement.
CHAPTER 3
SELECTION CRITERIA OF CUPOLA FURNACE FOR
FABRICATION

Cupolas are rated by number from 0 to 12 and vary in capacity designated as melting rate in tons per hour from approximately 1 to 35 tons per hr. The selection criteria are

1. Portable
2. Uses low floor space
3. Able to explain the working conditions
4. Cost effective

From the various sizes of cupola size 2 cupolas is taken for fabrication in the ratio 1:2. Since it meets up with the selection criteria, i.e. it is not as small as size 0 and 1 and not very large. In shortly it could be easily constructed and able to explain the working conditions. The size 2 cupola is handy as well as transported at ease.

<table>
<thead>
<tr>
<th>Cupola size</th>
<th>Shell diam. in.</th>
<th>Diameter of lower lining, in.</th>
<th>Diam. inside lining, in.</th>
<th>Area inside lining, sq. in.</th>
<th>Melting rate, tons/hr with iron to coke ratio of</th>
<th>Coke and iron charges, lb</th>
<th>Bed total coke height above tuyeres, in.</th>
<th>Coke</th>
<th>Iron</th>
<th>Flux lb</th>
<th>Normal windbox pressure, in.</th>
<th>Suggested blower selection</th>
<th>Total area of tuyeres, sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27</td>
<td>4 1/2</td>
<td>18</td>
<td>204</td>
<td>11/4</td>
<td>13/16</td>
<td>23-24</td>
<td>39</td>
<td>18</td>
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<td>1250</td>
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<tr>
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<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

* From American Foundryman’s Society.
† Height of bed coke varies as square root of blast pressure.
‡ Recommended blowers with 30 on discharge pressure when air weight control is used.

A practical guide for determining the current of blast: Multiply the square root of the blast pressure by 10 and add 6. For example, suppose the blast pressure is 10 in. The square root of 16 is 4; 4 X 10.5 = 46 in. So the bed coke (for 46 in blast) should measure 61 in. above the tuyeres.
3.1 FABRICATION DIAGRAM

All dimensions in mm

1. Legs
2. Tap hole
3. Slag hole
4. Tuyeres
5. Wind box
6. Charging door
7. Spark arrestor
8. Brick lining
9. Sand bed
10. Drop doors
3.2 MELTING CAPACITY AND CHARGE CALCULATIONS

Volume of the molten metal that lies above the sand bed, \( V = \pi \times 17.5^2 \times 13.5 \)

\[ V = 12982 \text{ cm}^3 \]

\[ V = 0.012982 \text{ m}^3 \]

Density of cast iron

\[ \text{Density} = \frac{\text{mass}}{\text{volume}} = 7250 \text{ kg/m}^3 \]

Therefore the metal holding capacity

\[ = 94.12 \text{ kg} \]

3.3 MATERIALS REQUIRED

Quantity of sheet required

48 sq. feet

Quantity of 8mm dia iron rod required

21 meters

Quantity of \( \frac{3}{4} \)" hollow pipe

6.5 meters

Quantity of 25*25*6 angle iron

1 meter

Quantity of 6*3 ms flat

10 meters

Quantity of 50*8 ms rectangular pipe

4 meters
CHAPTER 4
FABRICATION DETAILS

First of all we have constructed or fabricated the skeleton of the cupola. The 8mm rod was cut into required pieces and hand rolled. The hand rolled pieces were tack welded and hammered to get finish and to get accurate dimensions.

After the rings were made it is welded with rods for stability of the skeleton. The rods gives the strength taking the whole loads.

After the skeleton the legs of the cupola are made out of rings and ms flat. The flat bars are welded to the rings.
Flat rectangular pipes are used as legs. They give the cupola an extra finish.

After the skeleton work the GI sheet was cut into pieces for making the tuyeres, wind box, spark arrester, etc.
The GI sheet was hand rolled to the skeleton and the tuyeres and other parts were gas welded to the main structure. Primer was also coated to the structure. Charging door was also gas cutted to the structure. The split doors were hinged at the wind box.

Then we made the charging platform and the ladder for accessing the charging platform. The charging platform needs to be below than the charging doors.
Then the interior of the cupola furnace were done. One part is fabricated as if it is working and the other as in it when not working using the split doors.

After the interior work the cupola erected with the help of clamps that is fastened with bolts to the charging platform. And the painting work is done.
CHAPTER 5
CONCLUSION

The size 2 cupola is fabricated in the ratio 1:2 and is able to explain all the working conditions as per the international standards.
BIBLIOGRAPHY

